UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA DENTÁRIA

COMPARATIVE ANALYSIS OF ROOT CANAL ANATOMY AFTER DIFFERENT MECHANICAL PREPARATION

FILIPA DOS SANTOS NETO

DISSERTAÇÃO

MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

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COMPARATIVE ANALYSIS OF ROOT CANAL ANATOMY AFTER DIFFERENT MECHANICAL PREPARATION

Filipa dos Santos Neto

Dissertação orientada

Pelo Prof. Doutor António Ginjeira

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Aos meus pais, por aquilo que sou e conquistei.

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RESUMO

INTRODUÇÃO: A Sociedade Europeia de Endodontia, define esta área da Medicina Dentária como a ciência que estuda a forma, função, saúde, lesões e doenças da polpa dentária e região perir radicular, a sua prevenção e tratamento.

Os objetivos da preparação de um canal radicular passam pela remoção do tecido pulpar remanescente, pela eliminação dos microorganismos, remoção de detritos e conformação cónica do canal com constrição apical mantida. A manutenção da anatomia original do canal é um fator de extrema importância para se alcançar os objetivos acima citados, sabendo-se que a existência de curvaturas acentuadas condiciona os resultados.

Na última década, têm-se assistido ao desenvolvimento de inúmeros modelos de instrumentos rotatórios de NiTi com diferentes configurações e desenhos com o objetivo de reduzir o tempo de preparação e simplificar o procedimento de preparação canalar. As técnicas de instrumentação mecanizada têm igualmente vindo a desenvolver-se mas, independentemente da técnica de instrumentação e material utilizado, a limpeza e modelagem do canal são procedimentos que, invariavelmente, levam à remoção de dentina das paredes dos canais, remoção esta que não deve ser excessiva num só sentido no interior do canal, mas sim em todas as direções, equidistante do eixo do canal, mantendo desta forma a anatomia inicial do mesmo.

OBJETIVO: O objetivo deste estudo passou pela avaliação da manutenção da anatomia original do canal após diferentes preparações mecânicas: ProTaper Universal™, ProTaper Next™ e Protaper Gold™.

MATERIAIS E MÉTODOS: A amostra era constituída por 36 canais com curvatura em forma de S. A partir destas 36 amostras foram constituídos três grupos de 12 canais, cada um preparado até um calibre de 0.25 mm e a um comprimento de 16 mm. Cada grupo de 12 foi instrumentado por um sistema rotatório diferente: Grupo A - ProTaper Universal™ ; Grupo B - ProTaper Next™; Grupo C - Protaper Gold™.

Para se proceder a uma análise quantitativa, foram tiradas a cada amostra uma foto antes e após a preparação mecânica que foram depois sobrepostas e tratadas no programa Rhinoceros Software. Neste programa de tratamento de imagem, foi determinado o eixo médio do canal e identificados os pontos de medição correspondentes às curvaturas coronais e apical, através da interceção de duas retas tangentes de cada curva

A largura do canal provocada pela instrumentação foi medida através da distância entre a margem do canal pré-instrumentado e a margem do canal pós-instrumentado através de uma aplicação de dimensões existente no programa. Estes valores, obtidos à escala real, permitem fazer a avaliação quantitativa da modificação da anatomia inicial do canal.

A segunda parte do estudo baseia-se numa avaliação qualitativa da existência ou não de retificação nas curvaturas coronal e apical e na presença ou não de transporte apical e se este é muito ou pouco significativo. Foram escolhidos nove examinadores, dois especialistas em endodontia, dois não especialistas e dois alunos para fazer a avaliação de nove imagens escolhidas de forma aleatória, três para cada grupo de instrumentos.

A análise estatística foi feita com ajuda do programa SPSS IBM®, com recurso ao teste Kolmogorov-Smirnov para identificação da distribuição normal dos resultados, tendo-se usado o teste não paramétrico Mann-Whitney post hoc U test de comparações múltiplas para a análise dos resultados com distribuição não normal e o teste paramétrico One-Way ANOVA para análise dos valores com distribuição normal, considerando os valores estatisticamente significantes com $p<0,05$. A análise descritiva dos resultados também foi feita com médias e desvio padrão.

RESULTADOS: As diferenças na preparação que os três sistemas de limas fazem na porção convexa da curvatura coronal não são estatisticamente significativas, contudo, na porção côncava do canal estas já apresentam uma diferença estatisticamente significativa, sendo que a ProTaper Universal™ é o sistema que introduz um maior alargamento enquanto a ProTaper Gold™ regista os menores valores.

A diferença na preparação que os três sistemas de limas fazem na porção côncava da curvatura apical é estatisticamente significante, sendo que a ProTaper Universal™ é novamente o sistema que introduz um maior alargamento, enquanto a ProTaper Gold™ regista um menor valor. Na porção convexa da curvatura apical, as diferenças entre a preparação do sistema ProTaper Universal™, ProTaper Gold™ e ProTaper Next™ são estatisticamente significantes, contudo, não há diferenças estatisticamente significantes entre a preparação executada por uma ProTaper Gold™ e uma ProTaper Next™ .

O sistema ProTaper Universal™ causa um alargamento significativamente maior no canal em comparação com os outros dois grupos, especialmente nos lados internos da curvatura apical e coronal, provocando a retificação do canal. O sistema ProTaper Gold™ os menores valores.

DISCUSSÃO: Para comparar a anatomia do canal após diferentes preparações mecânicas e para avaliar a manutenção da sua forma original, foram usados neste estudo canais simulados, normalizando as condições experimentais. Apesar de os blocos de resina nem sempre refletirem a verdadeira ação dos instrumentos em canais radiculares de dentes reais, os canais em forma de S, possivelmente por resultarem no aumento da dificuldade de instrumentação, têm sido relatados como sendo um bom instrumento para a avaliação das diferenças no desempenho dos instrumentos.

Para esta análise quantitativa é necessário ter em conta a possível introdução de vieses, tendo em consideração: o grau de incerteza do Software Rhinoceros, considerando 0,006; os dados dependentes da precisão do operador durante o procedimento experimental: manutenção do comprimento de trabalho exata; estabilização do bloco de resina durante a preparação mecânica.

ProTaper Gold™ originou significativamente uma menor modificação da curvatura coronal e apical em comparação ProTaper Universal™. No que diz respeito ao sistema ProTaper Next™ e comparando-o com o sistema ProTaper Universal™ , este novo sistema apresenta uma modificação significativamente menor apenas na curvatura apical, apesar do facto de promover no geral menos alargamento do canal. Estes resultados são consistentes com as conclusões do estudo de Shori et ai. 2.015, diz que a ProTaper Next™ é capaz de induzir menos defeitos dentinários do que o sistema ProTaper Universal™. Portanto, nas condições deste estudo, pode-se afirmar que ProTaper Gold™ é o sistema rotativo que tem mais respeito pela anatomia inicial do canal. Uma maior flexibilidade pode ser responsável pela manutenção da anatomia original do canal. Apesar da arquitetura e modo de utilização idênticos, os sistemas ProTaper Gold™ e ProTaper Universal™ diferem no que toca à flexibilidade, resistência à fadiga e à torção. Isto deve-se possivelmente aos diferentes processos de fabricação dos instrumentos, conferindo melhores propriedades aos sistemas ProTaper Gold™ .

A segunda etapa do estudo compreendeu uma análise qualitativa que avaliou a presença ou não de retificações nas curvaturas coronal e apical assim como a presença ou não de transporte apical. Na análise destes parâmetros participaram dois endodontistas, médicos dentistas não especialistas e alunos. As diferenças registadas entre estes três grupos pode dever-se a diferente experiência clínica e a diferentes níveis de

conhecimento na área da endodontia. A discrepância mais significativa registpu-se na avaliação do transporte apical em canais instrumentados por ProTaper Gold™, onde a sua manutenção foi confirmada apenas pela totalidade dos endodontistas. A retificação da curvatura apical em canais instrumentados por ProTaper Universal™ e a manutenção da anatomia inicial de canais instrumentados com ProTaper Gold™ são consistentes com os resultados quantitativos e entre os diferentes examinadores cegos. ProTaper Universal™ e ProTaper Next™ foram responsáveis por algumas irregularidades apicais

CONCLUSÃO: De acordo com as limitações deste estudo, ProTaper Gold™ foi o sistema rotativo que melhor manteve a anatomia original do canal em forma de S, com menos modificação das curvaturas coronal e apicais, revelando mais flexibilidade em relação aos sistemas ProTaper Next™ e ProTaper Universal ™ .

Por sua vez, ProTaper Universal ™ foi o sistema que originou a maior modificação do canal original, apresentando uma tendência significativa para a retificação da curvatura apical.

Durante a prática clínica, os médicos devem estar cientes das propriedades mecânicas dos instrumentos escolhidos para melhor adaptar um sistema rotativo para um caso específico. É importante respeitar a anatomia do canal original e evitar o transporte apical de modo que o tratamento endodôntico não seja comprometido.

Palavras-passe: ProTaper Next; ProTaper Universal; ProTaper Gold; instrumentos rotatórios; instrumentação canalar; endodontia

ABSTRACT

INTRODUCTION: Endodontology is concerned with the study of the form, function and health of, injuries to and diseases of the dental pulp and periradicular region, their prevention and treatment. To ensure the success of the endodontic tratment, is important to consider the respect by original root canal anatomy.

AIM: Evaluate the maintenance of the original canal anatomy when comparing three different rotary systems, ProTaper Universal^{TM}, ProTaper Next^{TM} and Protaper Gold^{TM}.

MATHERIALS AND METHODS: A quantitative analysis was made by measuring the canal with of 36 samples, distributed by three groups of twelve samples each (Group A -ProTaper Universal^{TM}, Group B - ProTaper Next^{TM} , Group C - Protaper Gold^{TM}, by superimposed images of pre and post instrumentation using Rhinoceros Software. In the qualitative analysis, blinded examiners evaluated three images from each group and refer the presence or absence of rectifications in the coronal and apical curvatures, as well as the presence of significant apical transportation. The statistical analysis was obtained using Kolmogorov-Smirnov test, Mann-Whitney post hoc multiple comparisons U test and One-Way ANOVA, with a significance of p<0,05.

RESULTS: Considering the inner side of both curvatures, differences between files are statistically significant (p<0,05), where the ProTaper Universal^{TM} system is responsible for a bigger widening, while ProTaper Gold^{TM} presents the smaller mean value.

DISCUSSION AND CONCLUSION: It might be assumed that ProTaper Gold^{TM} was the rotary system that has more respect for original canal anatomy. Higher flexibility might be the predominant propriety responsible by these results. ProTaper Universal ^{TM} was the system that originated the greatest modification of the original canal, presenting a significant tendency to straightened apical curvature.

KEYWORDS: ProTaper Next; ProTaper Universal; ProTaper Gold; rotary instruments; root canal shaping; endodontics

1. INTRODUCTION

1.1 Endodontics - definition

Endodontology is concerned with the study of the form, function and health of, injuries to and diseases of the dental pulp and periradicular region, their prevention and treatment; the principle disease being apical periodontitis, caused by infection. (Europea Society of Endodontology 2006). This definition stated by the European Society of Endodontology is very similar to the definition that is brought to us by the American Association of Endodontics – Endodontics is the branch of dentistry concerned with the morphology, physiology and pathology of the human dental pulp and periradicular tissues; its study and practice encompass the basic and clinical sciences including the biology of the normal pulp and the etiology, diagnosis, prevention and treatment of diseases and injuries of the pulp and associated periradicular conditions. These differences in definition reflect a different combination of words with the same content.

1.2 Endodontics aims

Root canal treatment is carried out when the pulp is non vital or has been removed to prevent or treat apical periodontitis. The objectives of preparation are to: remove remaining pulp tissue, eliminate microorganisms, remove debris and shape the root canal(s) so that the root canal system can be cleaned and filled. (European Society of Endodontology 2006; Vaudt et al. 2009). The desired canal configuration for prepared root canals should be a conical tapered canal with the smallest diameter and a marked stop at the apical constriction. Such adequate canal preparation becomes more difficult as root canal curvature increases. (Schäfer et al. 1996) Moreover, it has been suggested that canal geometry might also influence rotary instrument performance in terms of shaping outcomes. (Peters et al. 2003)

Schilder has stated that the final root canal preparation should be in conformation with the general shape and direction of the original canal may be the most neglected phase of endodontic treatment and that the greatest problems lie in attempting to maintain the canal curvatures in the apical regions. (Esposito et al. 1995)

1.3 Advances in mechanical rotary instruments

In the last decade, several rotary nickel–titanium (NiTi) instruments with different configurations and designs have been developed with the aim to reduce the preparation time and to simplify the preparation procedure. (Vaudt et al. 2009; Esposito et al. 1995) NiTi-alloy has the advantages of super elasticity and the shape memory effect, which can maintain the original canal curvature and create a tapered root canal shape. (Ding-ming et al. 2007; Yoshimine et al. 2005) The introduction of nickel-titanium (NiTi) instruments allowed a safer and easier preparation of canals with complex anatomic characteristics.

The rotary techniques of instrumentation significantly improved during the last few years, but regardless of the instrumentation technique, cleaning and shaping procedures invariably lead to dentin removal from the canal walls. Excessive dentin removal in a single direction within the canal rather than in all directions equidistantly from the main tooth axis causes what is known as canal transportation. (Hartmann et al. 2007) Many of these systems have been investigated with regard to their shaping and cleaning ability, handling safety, and working time. These studies have shown that NiTi instruments can effectively prepare continuously tapered and centered root canal forms exhibiting only minor deviations from the main axis of the root canal. (Vaudt et al. 2009; Thompson et al. 2000; Schäfer et al. 2001)

However, in clinical practice these instruments carry a risk of fracture, mainly as a result of flexural (fatigue fracture) and torsional (shear failure) stresses. Canal curvature is suspected to be the predominant risk factor for instrument failure caused by flexural stresses. This risk might be reduced by performing coronal enlargement and manual preflaring to create a glide path before using NiTi rotary instrumentation. Thus the root canal diameter should be bigger than or at least the same size as the tip of the first rotary instrument used. (Berutti et al.2009). It is commonly advocated to explore and shape a root canal with a #15 or #20 hand instrument before using a rotary NiTi instrument to full working length to create a glide path for the safe advancement of the rotary instrument tip. The creation of a rotary glide path has shown advantages compared to traditional hand file preparation: better preservation of the canal anatomy and fewer aberrations, and less incidence of postoperative pain. (Arias et al. 2015)

Considering this, in this study, mechanical preparation of the S-shaped canals was preceded by a ProGlider™.

Improved flexibility of endodontic files is another factor that might reduce iatrogenic errors resulting from canal transportation, and the efficiency and safety of root canal treatment, increasing it. The geometry and composition of the metal and its thermomechanical improvements affect the flexibility of NiTi rotary files. (Uygun et al. 2015)

1.3.1 NiTi alloys

In the early 1960s, a nickel–titanium alloy was developed by W. F. Buehler, a metallurgist investigating nonmagnetic, salt resisting, waterproof alloys for the space program at the Naval Ordnance Laboratory in Silver Springs, Maryland, USA

The alloy was named Nitinol, an acronym for the elements from which the material was composed; *ni* for nickel, *ti* for titanium and *nol* from the Naval Ordnance Laboratory. Nitinol is the name given to a family of intermetallic alloys of nickel and titanium which have been found to have unique properties of shape memory and super-elasticity.

The super-elastic behavior of Nitinol wires means that on unloading they return to their original shape before deformation. As the alloy has greater strength and a lower modulus of elasticity compared with stainless steel, there may be an advantage in the use of NiTi instruments during the preparation of curved root canals, because the files will not be permanently deformed as easily as it would happen with traditional alloys.

The nickel–titanium alloys used in root canal treatment contain approximately 56% (wt) nickel and 44% (wt) titanium. They have a nearly equiatomic ratio of nickel and titanium and can exist in various crystallographic forms. Their properties are intimately connected with their inherent ability to alter their type of atomic bonding with temperature and stress, which causes unique and significant changes in the mechanical properties and crystallographic arrangement.

Because of their super-elasticity, nickel–titanium alloys are being used increasingly in the construction of endodontic instruments. (Thompson 2000)

Tulsa Dental introduced nickel-titanium to endodontics with the ProFile® Series 29® rotary file in 1994. (DENTSPLY Tulsa Dental Specialties)

1.3.2 M-Wire NiTi alloy

Thermomechanical processing is frequently used to optimize the microstructure and transformation behavior of NiTi alloys, which in turn has greater influence on the mechanical properties of NiTi files. (Hieawy et al. 2015)

One of many promising solutions to improve fatigue resistance of rotary instruments is to optimize the microstructure of NiTi alloys through novel thermomechanical processing or new manufacturing technologies. Tulsa Dental Specialties introduced the M-Wire NiTi technology in 2007. This new NiTi wire has been developed through a proprietary thermomechanical processing procedure and showed significantly improved cyclic fatigue resistance on endodontic rotary instrument products in comparison with those made of conventional super elastic NiTi alloys. M-Wire contains all 3 crystalline phases, including deformed and microtwinned martensite, R-phase, and austenite, being a more flexible alloy. (Ye et al. 2012; Arias et al. 2015; DENTSPLY Tulsa Dental Specialties)

1.4 Rotary instruments

The purpose of this study was to consider the maintenance of a canal anatomy and the incidence of canal transportation when comparing three different rotary systems, ProTaper Universal™, ProTaper Next™ and Protaper Gold™, with the glide path established by ProGlider™ .

1.4.1 ProGlider™

ProGlider™ is a single file glide path instrument made of M-Wire alloy that features a variable progressive taper of 2–8.5 % with a tip size 16.02. (Figure 1) The manufacturer advocates that it creates a glide path faster than hand files or any other alternative rotary glide path solutions. Its usage parameters are established in manufacturer's recommendations which are 300 rpm and torque preset between 2 and 2,5 N cm. (Arias et al. 2015; DENTSPLY Tulsa Dental Specialties)

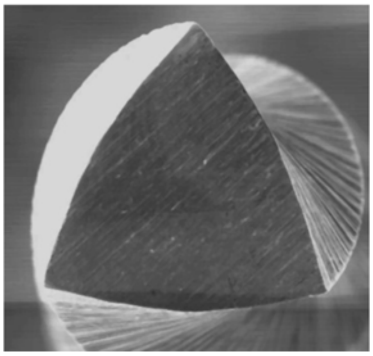
Figure 1 – ProGlider^{TM} file, a single file glide path instrument made of M-Wire alloy (Dentsply Maillefer

1.4.2 ProTaper Uneversal^{TM}

ProTaper Universal^{TM} is made of conventional Ni-Ti wire and has been widely used in root canal treatment for the past decade. (Wu et al. 2015).

The fully set of files is represented in Figure 2 and it is composed by too shaping files, S1 and S2, responsible for shaping the coronal and mesial portion of the canal with brushing movements and the finishing files, F1, F2, F3, F4 and F5, which prepare the apical portion of the canal an only can be used until they reach the full working length, without brushing movements, all in different lengths (21, 25 and 31 mm). These files have, in sequence, purple (S1), white (S2), yellow (F1), red (F2), blue (F3), double black (F4) and double yellow (F5) identification rings corresponding to sizes 18/02, 20/04, 20/07, 25/08, 30/09, 40/06 and 50/05. Sx shaper file is used to improve the canal access, size 19/04. Sx, S1, S2, F1 and F2 have a convex triangular cross section that is responsible for giving them resistance. (Figure 3). F3, F4 and F5, present a different section, this time a concave triangular cross section, giving them some flexibility. (Figure 4) These files, manufactured with a variable taper over the length of the cutting blades, with noncutting tips, have a rotation center coinciding with their mass center. (Hieawy et al; Dentsply Maillefer)

Figure 2 – ProTaper Universal^{TM} system composed by the shaping and finishing files (Dentisply Maillefer)



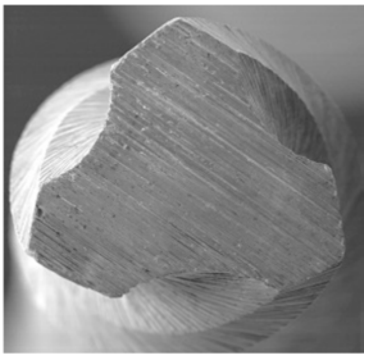


Figure 3 and Figure 4 – Sx, S1, S2, F1 and F2 convex triangular cross section and F3, F4 and F5 concave triangular cross section, respectively

1.4.3 ProTaper Next™

The ProTaper Next™ rotary file system **(**Figure 5**)** had its market debut on April 2013, and, according to the manufacturers, these files are the convergence of three significant design features: progressive percentage tapers on a single file, M-wire® technology and the off-set configuration. This system is composed by five files, X1, X2, X3, X4 and X5, all in different lengths (21, 25 and 31 mm) and with the same rectangular cross section, used with brushing movements **(**Figure 6**).** These files have, in sequence, yellow, red, blue, double black and double yellow identification rings corresponding to sizes 17/04, 25/06, 30/07, 40/06 and 50/06 respectively.

The rectangular cross section along with the non-coincidence between the rotation center and the mass center of the file, results in a limited contact of the cutting blades with the dentin wall, where only two points of the rectangular cross section are responsible for cutting. The rotation movement is this way asymmetric. The lack of contact between the cutting blade and the dentin wall creates a space inside the canal which allows a better derby removal, a reduction in the screw effect and the unwanted taper lock. (Shori et al. 2015; Dentsply Maillefer)

Figure 5 – ProTaper Next™ system composed by X1, X2, X3, X4 and X5. (Dentsply Maillefer)

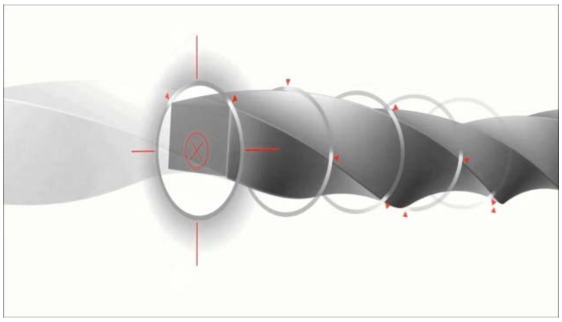


Figure 6 – ProTaper Next™ rectangular cross section (Dentsply Maillefer)

1.4.4 ProTaper Gold™

ProTaper Gold™, from all the above mechanical systems, is the one which entered the market most recently. The ProTaper Gold™ files have a design that features identical geometries as ProTaper Universal™ have been developed with proprietary advanced metallurgy. The manufacturer claims that these instruments have more flexibility and a fatigue resistance superior to ProTaper Universal™. However, most of the properties of this system have not been examined. (Hieawy et al. 2015)

The set of files is represented in Figure 7 and it is composed by two shaping files, S1 and S2, responsible for shaping the coronal and mesial portion of the canal with brushing movements and the finishing files, F1, F2, F3, F4 and F5, which prepare the apical portion of the canal an only can be used until they reach the full working length, without brushing movements, all in different lengths (21, 25 and 31 mm). These files have, in sequence, purple (S1), white (S2), yellow (F1), red (F2), blue (F3), double black (F4) and double yellow (F5) identification rings corresponding to sizes 18/02, 20/04, 20/07, 25/08, 30/09, 40/06 and 50/05, the same features as ProTaper Universal^{TM}. Sx shaper file is used to improve the canal access, size 19/04. Sx, S1, S2, F1 and F2 have a convex triangular cross section and F3, F4 and F5, present a concave triangular cross section. The only difference between ProTaper Gold^{TM} and ProTaper Universal^{TM} is comprised by the different size of the handle, being smaller in this new system, eleven millimeters compared to the thirteen from the original system. According to the manufacture, this smaller handle allows improved accessibility to teeth.

Figure 7 - ProTaper Gold^{TM} system composed by the shaping and finishing files (Dentisply Tulsa Dental Specialties)

2. AIMS

The purpose of this study was to compare the morphological characteristics of prepared canals with an S-shaped curvature in clear resin blocks by the use of three rotary files: ProTaper Universal^{TM}, ProTaper Next^{TM} and Protaper Gold^{TM}

In a double curve canal, is important to understand whether the shaping effect is bigger in the inner or outer portion of the curvature and whether the shaping effect is more significant in the coronal or apical curvature.

3. MATERIALS AND METHODS

3.1 Canal instrumentation

A total of 36 simulated canal with an S-shaped curvature in clear resin blocks (ISO 15, Endo-Training-Bloc-S .02 Taper; Dentsply-Maillefer, Ballaigues, Switzerlan) (Figure 8) were prepared by three different Ni-Ti rotary files system, using the technique recommended by the manufacturer: ProTaper Universal TM (Dentsply Maillefer); ProTaper Next TM (Dentsply Maillefer); ProTaper Gold TM (Dentsply Tulsa Dental Specialties)

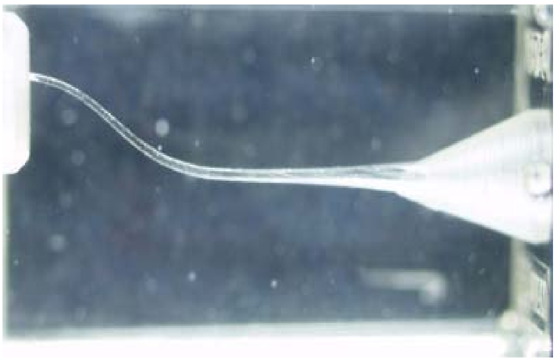


Figure 8 - S-shaped curvature in clear resin blocks (ISO 15, Endo-Training-Bloc-S .02 Taper; Dentsply Maillefer, Ballaigues, Switzerlan)

Out of the 36 simulated canal resin blocks, three groups of 12 resin blocks were made, each one prepared by one of the rotary system files above: Group A – 12 simulated canal resin blocks, prepared with ProTaper Universal TM (Dentsply Maillefer) (Figure 9); Group B – 12 simulated canal resin blocks, prepared with ProTaper Next TM (Dentsply Maillefer) (Figure 10); Group C – 12 simulated canal resin blocks, prepared with ProTaper Gold TM (Dentsply Tulsa Dental Specialties) (Figure 11).

Each simulated canal was prepared to a working length of 16 millimeters, at a speed of 300 rpm and a torque-control level of 40, as the suggested settings, using a reduction hand-piece powered by an electric motor (Tecnika, Dentsply Maillefer, Schools Grant Program) (Figure 12). The final apical preparation in Group A was set to F2, in Group B set to X2 and in Group C was set to F2. Copious irrigation with water was performed after the use of each file, using a disposable syringe and 27 gauge irrigation needle.

Figure 9 – Sterilized ProTaper Universal^{TM} Kit, Sx-F3, 25mm (Dentsply Maillefer)

Figure 10 – Sterilized ProTaper Next^{TM} Kit, X1-X3, 25mm (Dentsply Maillefer)

Figure 11 – Sterilized ProTaper Gold^{TM} Kit, Sx-F3, 25mm (Dentsply Tulsa Dental Specialties

Figure 12 - Electric motor (Tecnika, Dentsply Maillefer, Schools Grant Program)

All canals were prepared by the same operator. Only 6 resin blocks were prepared at a time to minimize operator fatigue. The operator had little experience using rotary files.

The following preparation sequences were made, after all canal were scouted up to the working length with a #10 stainless-steal k-file (Dentsply Maillefer) and a ProGlider™ (Dentsply-Maillefer) (Figure 13):

Group A

ProTaper Universal ™ files were set into rotation. Instrumentation followed the sequence below, using shaping files up to the working length with brushing movements and using finishing files with in-and-out movements until reach the working length:

1º A 2% taper, size 18 instrument – S1
2º A 4% taper, size 20 instrument – S2
3º A 7% taper, size 20 instrument – F1
4º A 8% taper, size 25 instrument – F2

Group B

ProTaper Next ™ files were set into rotation. Instrumentation followed the sequence below, with in-and-out movements until reach the working length:

1º A 4% taper, size 17 instrument – X1
2º A 6% taper, size 25 instrument – X2

Group C

ProTaper Gold ™ files were set into rotation. Instrumentation followed the sequence below, using shaping files up to the working length with brushing movements and using finishing files with in-and-out movements until reach the working length:

1º A 2% taper, size 18 instrument – S1

2º A 4% taper, size 20 instrument – S2

3º A 7% taper, size 20 instrument – F1

4º A 8% taper, size 25 instrument – F2

Figure 13 – Setilized ProGlider Kit, six files, 25mm (Dentsply Maillefer)

3.2 Image analysis

Pre instrumentation and post instrumentation images were recorded using a DSLR (Digital Single-lens Reflex) camera (Olympus Digital Camera E500) with a macro lens, using a shutter speed of 1.6 seconds and a 22 F-stop.

The footage was standardized: a landmark was made in each sample as a reference; the samples were all shot at the same distance and placed in the same position using a miter. To accomplish this, a reproduction table was used. (Kaiser Fototechnik GmbH & Co.KG) (Figure 14)

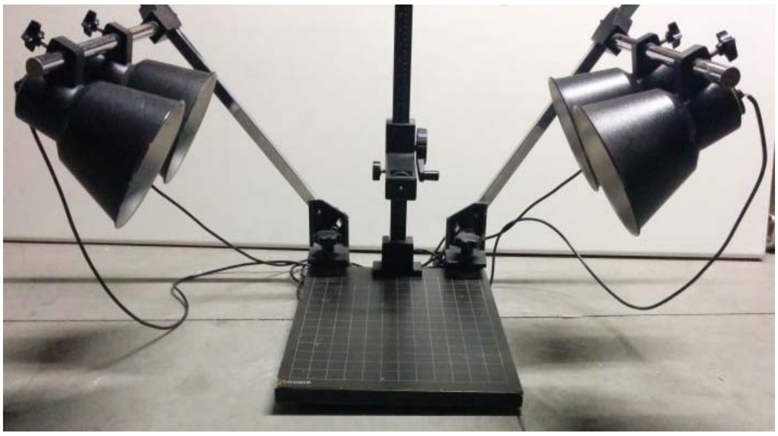


Figure 14 – Reproduction table (Kaiser Fototechnik GmbH & Co.KG)

The Rhinoceros Software (version 5.0; Robert McNell & Associates, Seattle, WA) was used to identify the mean axis of the canal from the pre instrumentation images (Figure 15) and to identify the measure points, corresponding to the coronal and apical curvatures. These measure points resulted from the interception of two tangent lines of each curve, drew by specific curve applications from the program as the sequence is shown below on Figure 16.

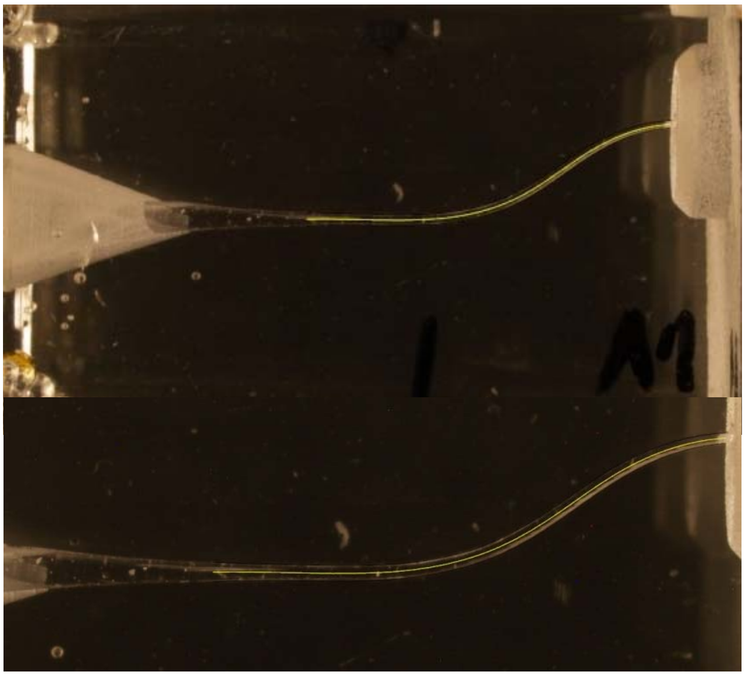


Figure 15 – Identification of the mean axis of the canal using the Rhinoceros Software version 5.0

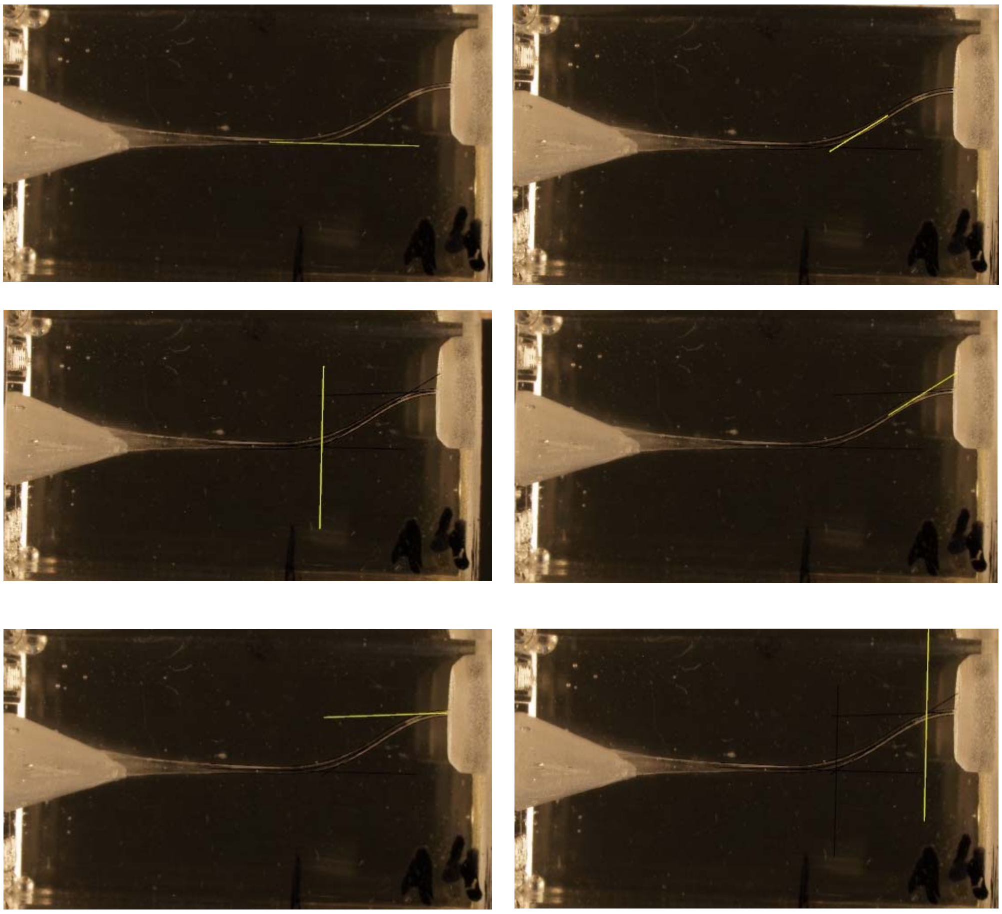


Figure 16 – This six pictures show the sequence made in the Rhinoceros Software to define the measure point of the coronal and apical curvature of the S-shape canal. Two tangent of each curve were trace and intercepted: first coronal curvature tangent; second coronal curvature tangent; interception of the two coronal curve tangent – measure point; first apical curvature tangent; second apical curvature tangent; interception of the two apical curve tangent – measure point.

The post instrumentation digital images were superimposed over the pre instrumentation images. This was accomplished by reducing the opacity of the post instrumentation images, done in a digital imaging software (Adobe Photoshop, version CS6; Adobe Systems Inc, San Jose, Ca) (Figure 17)

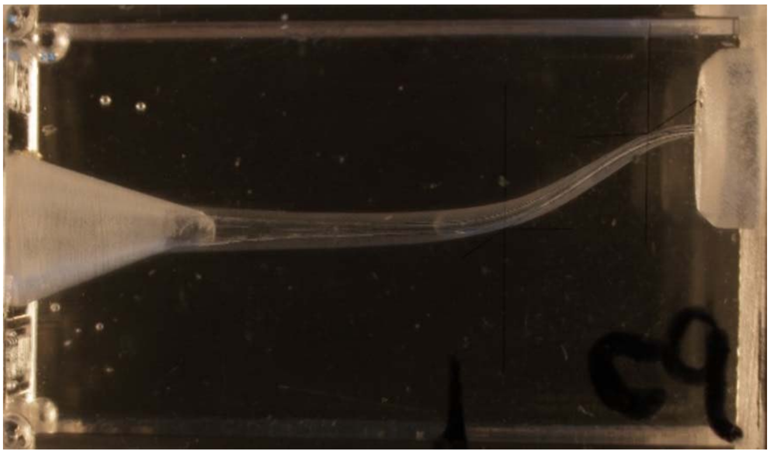


Figure 17 - Post instrumentation digital image superimposed over the pre instrumentation image (Adobe Photoshop, version CS6; Adobe Systems Inc, San Jose, Ca)

The canal with was assessed by measuring the distance from the center of the canal to the inner and outer margins of the prepared curve canal with specific dimension displays of the program. The distance between the margin of the pre instrumentation canal and de the margin of the prepared canal were also registered. Rhinoceros Software allowed to get real measures. These paired images and the measures obtained give a quantitative evaluation of the incidence of canal transportation after mechanical preparation.

To proceed with qualitative analysis, a compilation of questions were made to three different groups of blinded examiners:

Group 1: two endodontics specialists

Group 2: two inexpert clinicians

Group 3: two pre-graduated students.

The examiners evaluated three images, randomly chosen, from each group. The images were set by a random sequence and the blinded examiners had to refer the presence or absence of rectifications in the coronal and apical curvatures, as well as the presence of significant apical transportation.

3.3 Statistical analysis

The statistical analysis was obtained using the IBM ® SPSS ® Statistics version 22.0.0 software. Descriptive statistical analysis was performed to each group (A, B and C). In each experimental group mean and standard deviation were calculated for the inner and outer coronal and apical curvatures values.

The Kolmogorov-Smirnov test for was used to evaluate the data normality. The null hypothesis were the following, set for inner and outer coronal and apical curvatures values:

1. H0: The distribution of ICC is normal with mean 0,324 and standard deviation 0,04
2. H0: The distribution of OCC is normal with mean 0,101 and standard deviation 0,03
3. H0: The distribution of IAC is normal with mean 0,232 and standard deviation 0,07
4. H0: The distribution of OAC is normal with mean 0,040 and standard deviation 0,03

The data corresponding to the inner coronal curvature and to the outer apical curvature didn't follow a normal distribution, therefore, the first and last null hypothesis were rejected. The Mann-Whitney post hoc multiple comparisons U test, a non-parametrical test, was use to evaluate the differences among the inner coronal curve and outer apical curve data while the One-Way ANOVA, a parametric test, evaluated the differences among the other two groups. Differences were considered statistically significant when $p<0,05$.

4. RESULTS

4.1 Quantitative results

The results of the experimental procedure regarding the distance between the margin of the pre instrumentation canal and de the margin of the prepared canal and the distance from the mean axis of the canal to the inner and outer margins of the prepared curve canal are displayed in the following tables. The experimental procedure was repeated for the three groups: A (Table 1), B (Table 2) and C (Table 3).

Group A	Coronal curve				Apical curve			
	Inner (mm)		Outer (mm)		Inner (mm)		Outer (mm)	
A1	0,36	0,48	0, 09	0,21	0,34	0,44	0,01	0,11
A2	0,36	0,48	0,15	0,26	0,35	0,46	0,00	0,10
A3	0,40	0,51	0,08	0,20	0,31	0,40	0,06	0,14
A4	0,39	0,51	0,08	0,19	0,31	0,40	0,05	0,13
A5	0,36	0,48	0,06	0,21	0,24	0,35	0,00	0,09
A6	0,37	0,49	0,09	0,22	0,23	0,31	0,04	0,13
A7	0,38	0,49	0,10	0,22	0,32	0,41	0,05	0,15
A8	0,45	0,55	0,11	0,23	0,39	0,48	0,00	0,10
A9	0,35	0,46	0,12	0,24	0,29	0,39	0,00	0,11
A10	0,27	0,40	0,15	0,28	0,36	0,40	0,00	0,10
A11	0,35	O,47	0,14	0,27	0,32	0,42	0,00	0,11
A12	0,36	0,49	0,12	0,24	0,29	0,38	0,04	0,13

Table 1 - Group A – ProTaper Universal^{TM}. Measures obtained with the Rhinoceros Software. Every left column of the inner and outer variables regard the distance between the margin of the pre instrumentation canal and the margin of the prepared canal and very right column regard the distance from the center of the canal to the inner and outer margins of the prepared curve canal .

Group B	Coronal curve				Apical curve			
	Inner (mm)		Outer (mm)		Inner (mm)		Outer (mm)	
B1	0,37	0,49	0,05	0,17	0,19	0,31	0,05	0,17
B2	0,32	0,43	0,05	0,20	0,14	0,23	0,08	0,17
B3	0,30	0,41	0,08	0,22	0,23	0,36	0,00	0,11
B4	0,31	0,41	0,11	0,23	0,21	0,32	0,05	0,16
B5	0,34	0,45	0,09	0,21	0,26	0,38	0,03	0,14
B6	0,32	0,45	0,10	0,22	0,24	0,32	0,01	0,16
B7	0,29	0,41	0,07	0,17	0,20	0,29	0,06	0,15
B8	0,28	0,40	0,10	0,22	0,22	0,34	0,06	0,16
B9	0,30	0,42	0,14	0,23	0,24	0,34	0,03	0,13
B10	0,32	0,44	0,07	0,21	0,16	0,26	0,08	0,19
B11	0,32	0,44	0,11	0,23	0,28	0,40	0,04	0,17
B12	0,33	0,48	0,09	0,21	0,23	0,32	0,07	0,18

Table 2 - Group B – ProTaper Next^{TM}. Measures obtained with the Rhinoceros Software. Every left column of the inner and outer variables regard the distance between the margin of the pre instrumentation canal and de the margin of the prepared canal and very right column regard the distance from the center of the canal to the inner and outer margins of the prepared curve canal.

Group C	Coronal curve				Apical curve			
	Inner (mm)		Outer (mm)		Inner (mm)		Outer (mm)	
C1	0,32	0,43	0,12	0,22	0,19	0,28	0,04	0,13
C2	0,28	0,40	0,14	0,27	0,20	0,30	0,04	0,13
C3	0,28	0,42	0,11	0,23	0,14	0,24	0,04	0,15
C4	0,32	0,45	0,09	0,20	0,18	0,29	0,07	0,16
C5	0,31	0,41	0,12	0,22	0,17	0,25	0,08	0,17
C6	0,28	0,40	0,13	0,27	0,20	0,30	0,04	0,14
C7	0,30	0,41	0,12	0,23	0,17	0,27	0,06	0,17
C8	0,28	0,38	0,12	0,23	0,15	0,22	0,06	0,16
C9	0,26	0,36	0,09	0,20	0,13	0,22	0,04	0,16
C10	0,29	0,41	0,10	0,23	0,18	0,27	0,06	0,16
C11	0,29	0,38	0,12	0,23	0,15	0,25	0,04	0,18
C12	0,25	0,39	0,11	0,24	0,15	0,24	0,07	0,17

Table 3 - Group C – ProTaper Gold^{TM}. Measures obtained with the Rhinoceros Software. Every left column of the inner and outer variables regard the distance between the margin of the pre instrumentation canal and de the margin of the prepared canal and very right column regard the distance from the center of the canal to the inner and outer margins of the prepared curve canal.

Mean ratio A		Mean ratio B		Mean ratio C		Total	
Coronal	Apical	Coronal	Apical	Coronal	Apical	Coronal	Apical
0,238333	0,52	0,215278	0,48	0,211389	0,4175	0,221667	0,4725

Table 4 – The distance from the mean axis of the canal to the inner and outer margins of the prepared canal were summed, resulting in the total width of the post instrumentation canal. This total width was divided by the correspondent diameter of the file, giving us a ratio. This table presents the mean ratio for each group. Inside each group, by directly comparing coronal and apical ratio, is possible to understand which curvature lost more material.

Descriptive statistics of the four variables was done. The mean width and standard deviation for each experimental group are displayed in table 5.

	Coronal Curvature		Apical Curvature	
	Inner (mm)	Outer (mm)	Inner (mm)	Outer (mm)
A – ProTaper Universal	0,37 ± 0,04	0,10 ± 0,04	0,31 ± 0,05	0,02 ± 0,03
B – ProTaper Next	0,32 ± 0,02	0,09 ± 0,03	0,22 ± 0,04	0,0 5 ± 0,03
C – ProTaper Gold	0,29 ± 0,02	0,11 ± 0,02	0,17 ± 0,02	0,0 5 ± 0,02

Table 5 – Canal width in the measure points of the coronal and apical curvatures.

Differences between the three files systems canal preparations on the outer side of the coronal curvature are not statistically significant, however, in its inner side, these differences are statistically significant, where the ProTaper Universal^{TM} system is responsible for a bigger widening, while ProTaper Gold^{TM} presents the smaller mean value.

Concerning the inner side of the apical curvature, the differences between the three files systems canal preparations is statistically significant, where the ProTaper Universal^{TM} is, once more, responsible for a bigger widening, while ProTaper Gold^{TM} presents the smaller mean value. In the outer side of the apical curvature, differences in the canal preparation between ProTaper Universal^{TM}, ProTaper Next^{TM} and ProTaper

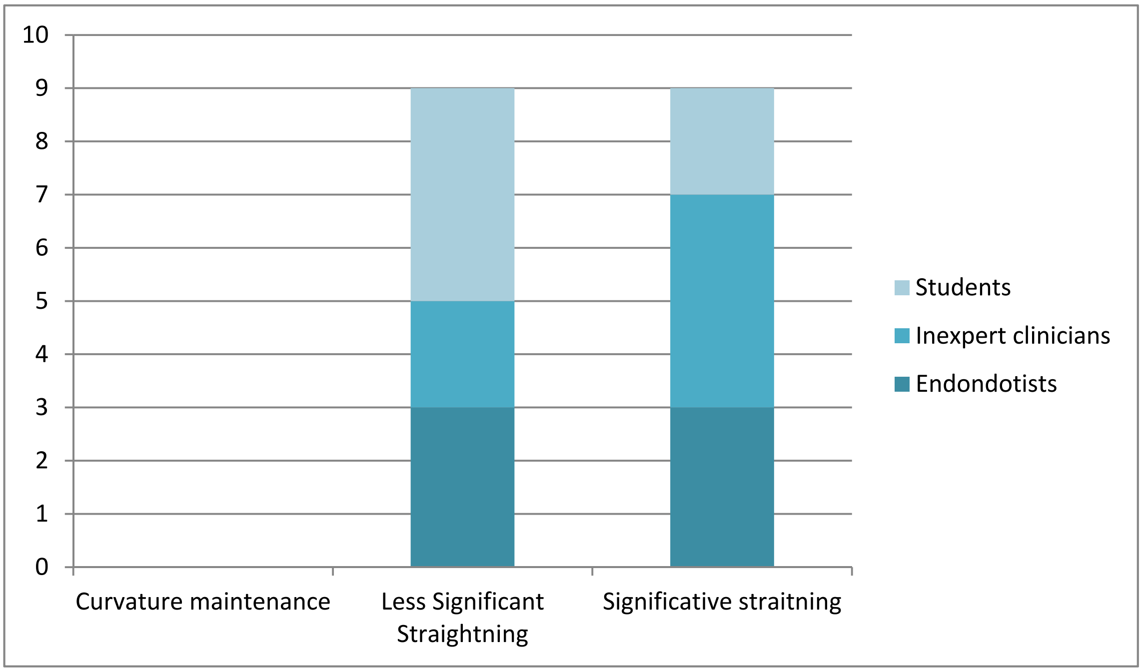
Gold™ are statistically significant, however, differences between ProTaper Next™ and ProTaper Gold™ are not statistically significant.

The ProTaper Universal™ system caused significantly greater widening of canals than the other two groups, especially at the inner sides of both curved regions, tending toward the straightening of the canal. The ProTaper Gold™ showed the lowest widening on both regions.

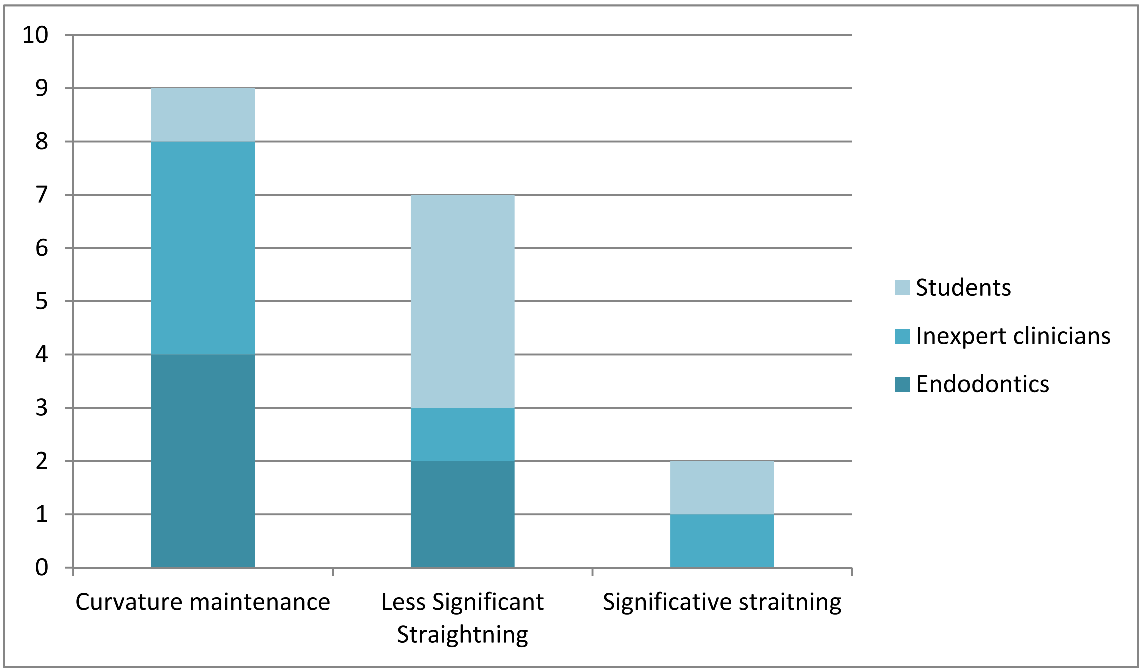
Additionally, every rotary file system removed more resin wall in the apical curve compared to the coronal curve.

4.2 Qualitative analysis

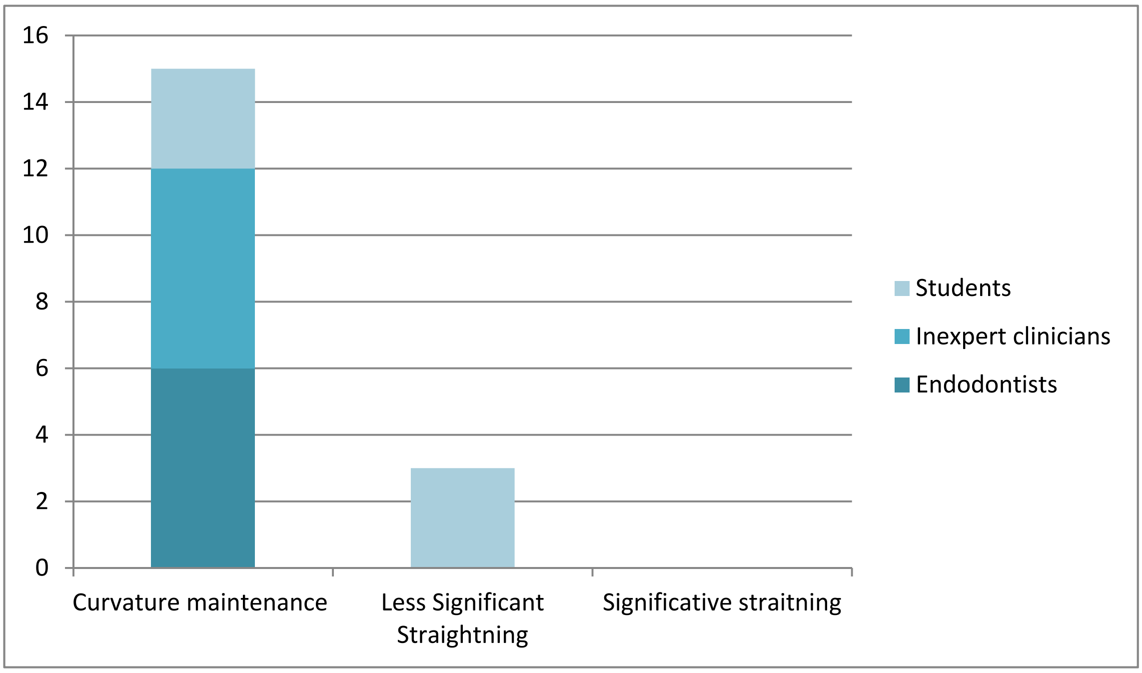
Considering each blinded examiners evaluation, the following graphics shows what was their evaluation concerning the presence or absence of rectifications in the coronal and apical curvatures, as well as the presence of significant apical transportation, for each system file.



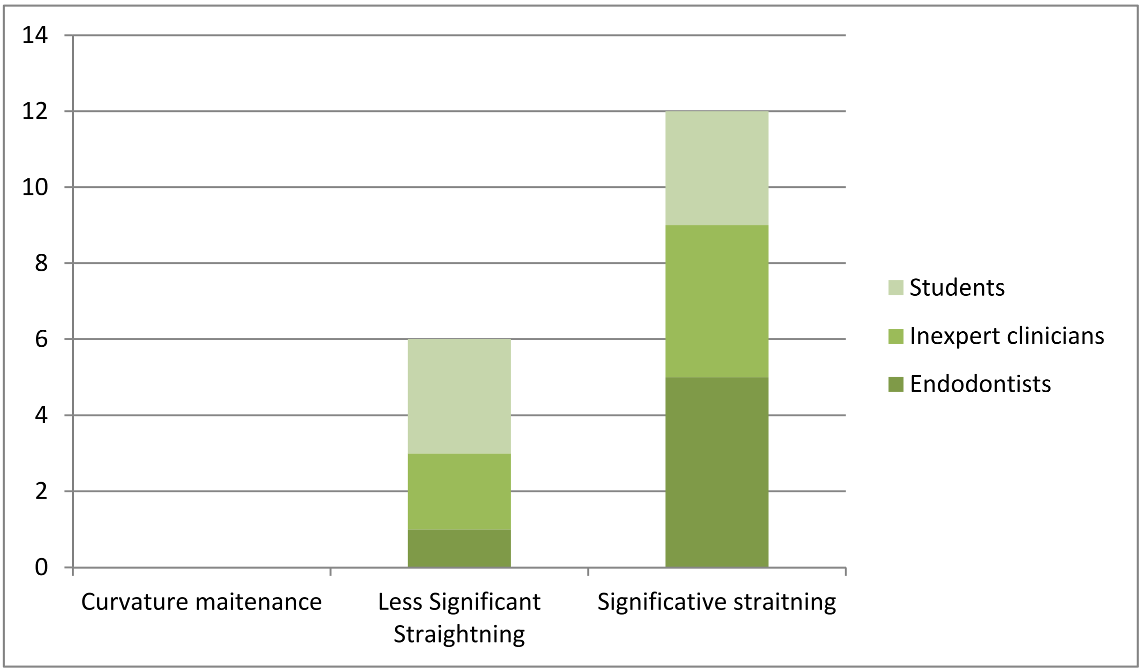
Graphic 1 – Evaluation of the coronal curvature prepared by ProTaper Universal™



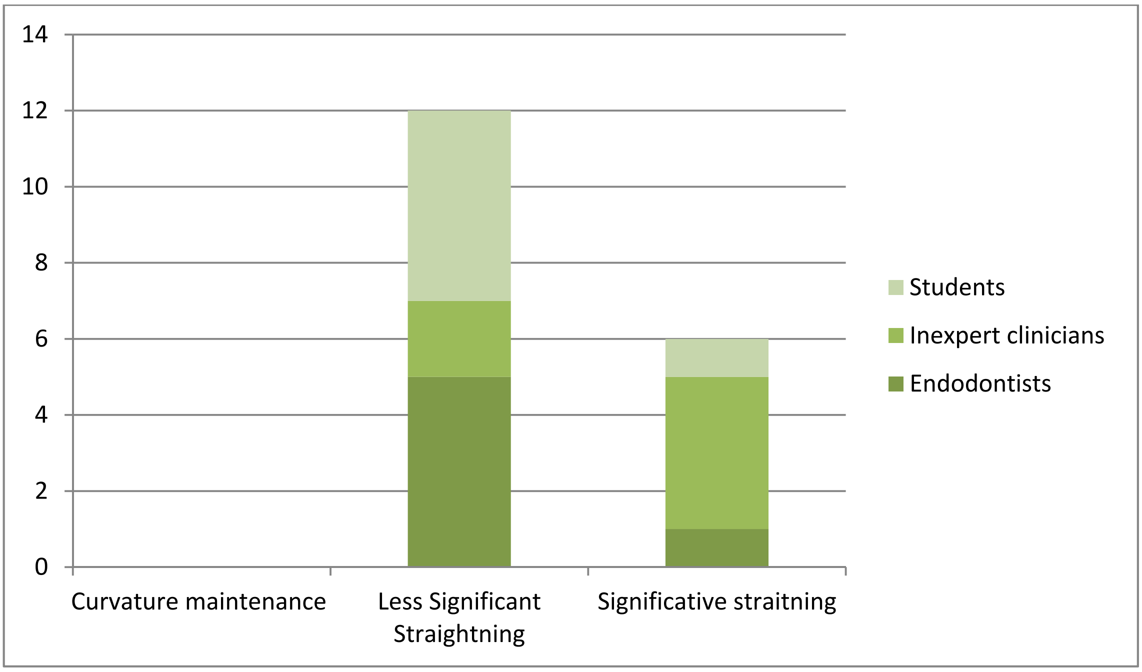
Graphic 2 – Evaluation of the coronal curvature prepared by ProTaper Next™



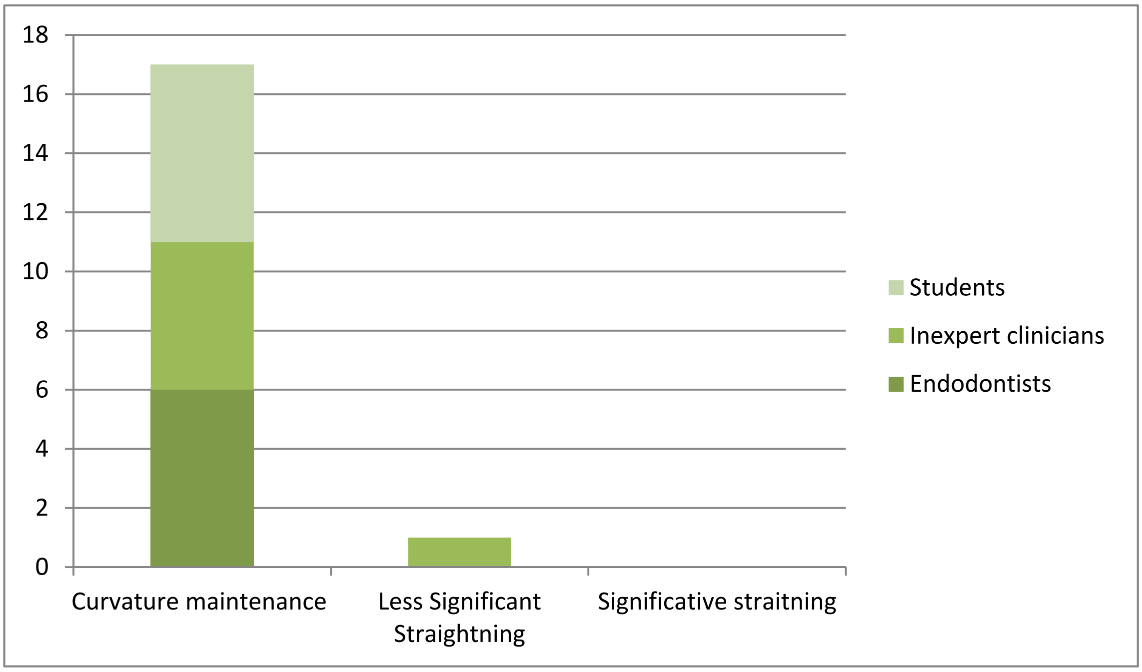
Graphic 3 – Evaluation of the coronal curvature prepared by ProTaper Gold™



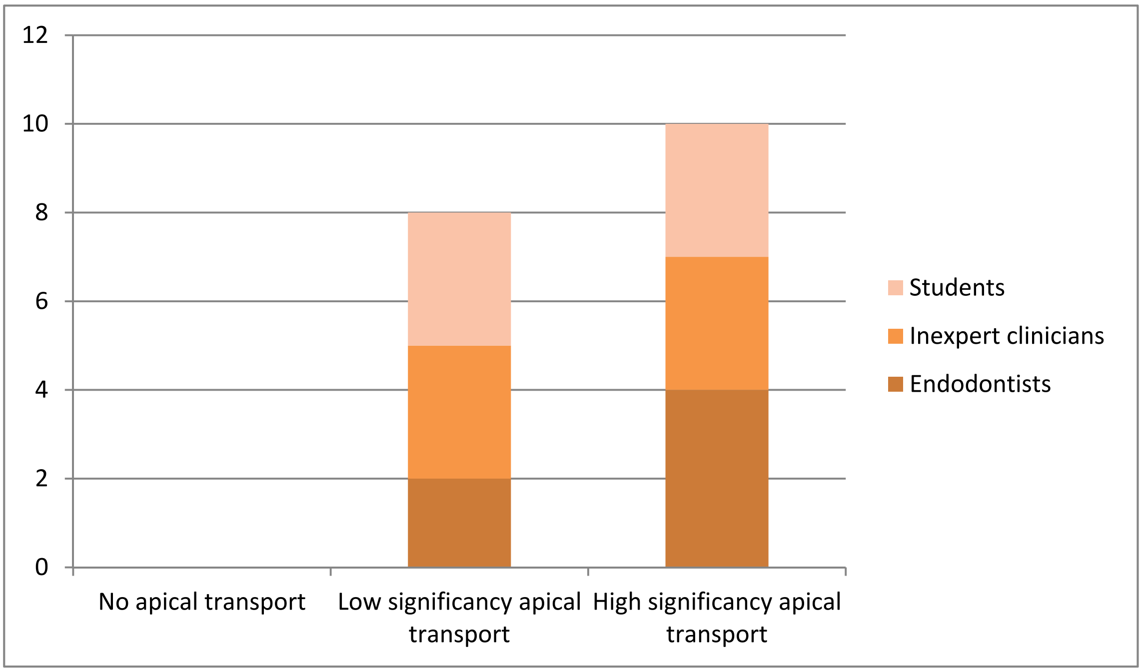
Graphic 4 – Evaluation of the apical curvature prepared by ProTaper Universal^{TM}



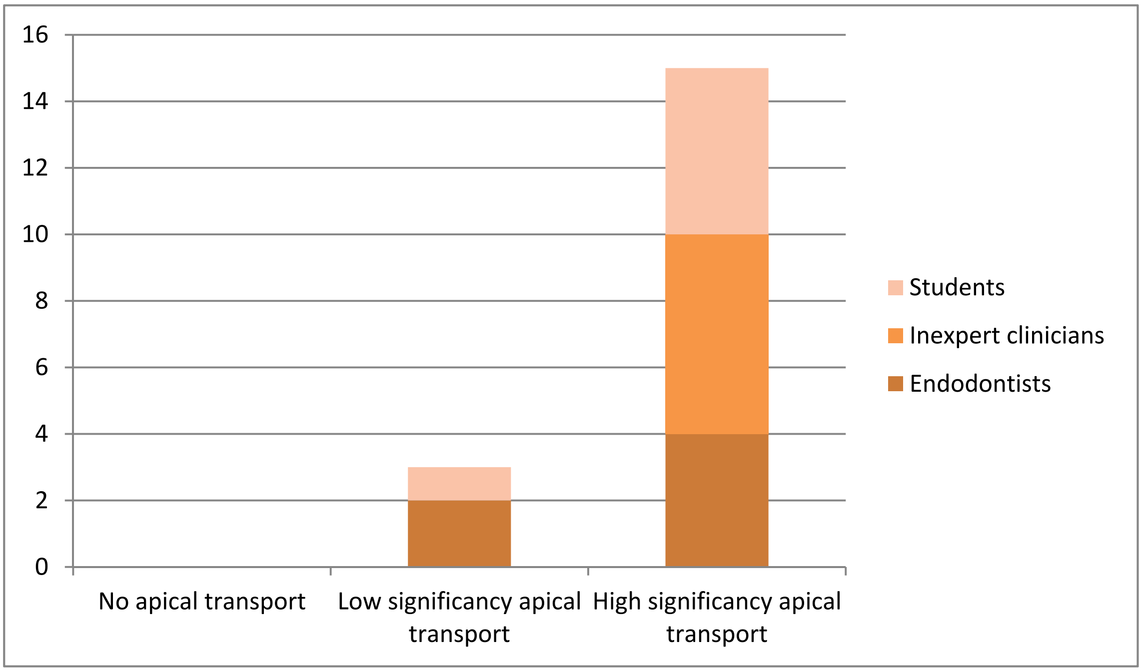
Graphic 5 – Evaluation of the apical curvature prepared by ProTaper Next^{TM}



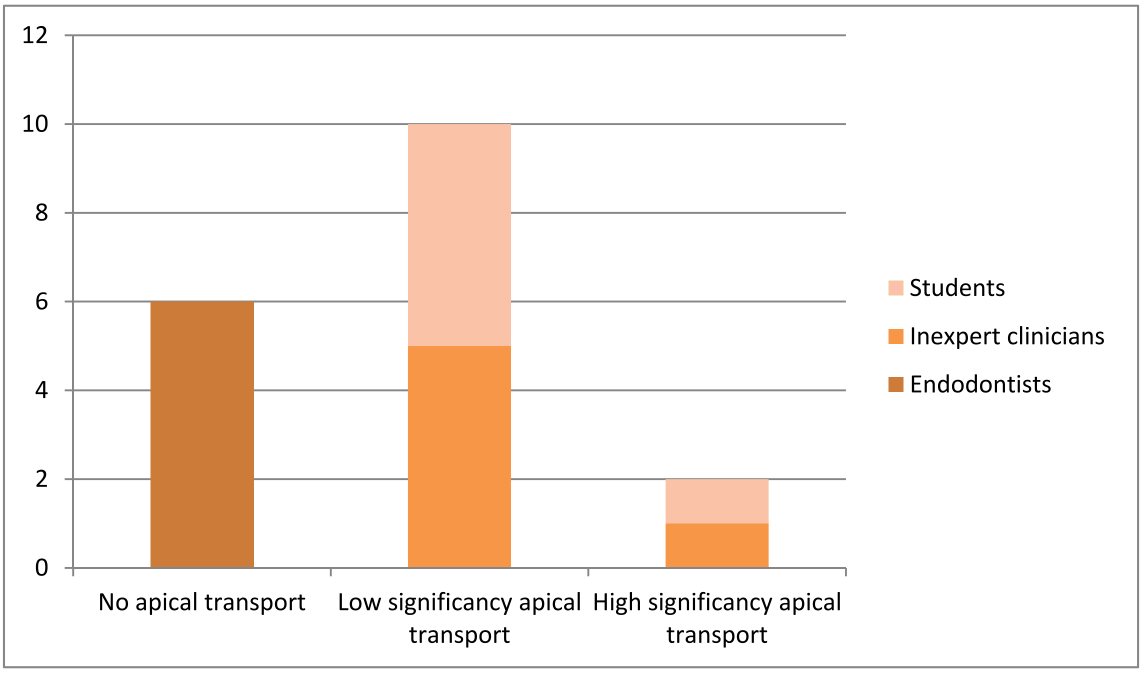
Graphic 6 – Evaluation of the apical curvature prepared by ProTaper Gold^{TM}



Graphic 7 – Evaluation of the apical transport, prepared by ProTaper Universal^{TM}



Graphic 8 – Evaluation of the apical transport, prepared by ProTaper Next™



Graphic 9 – Evaluation of the apical transport, prepared by ProTaper Gold™

The clinician's expertise (endodontist versus inexpert clinicians versus students) did not appear to have a significant impact in the following parameters:

1. Maintenance of the original shape of the canal by ProTaper Gold^{TM}
2. Maintenance of the original shape of the coronal curvature by ProTaper Next^{TM} and ProTaper Gold^{TM}
3. Straitening of the apical curvature by ProTaper Universal^{TM}
4. Apical transportation by ProTaper Next^{TM} and ProTaper Universal^{TM}

A significant difference is present when considering the apical transportation by ProTaper Gold^{TM}, where just endodontist evaluate as it is maintained.

5. DISCUSSION

Analysis of modifications in canal curvature after instrumentation has been widely used to evaluate the tendency of a technique, or of the mechanical properties of an instrument, to maintain the original canal anatomy or to straighten the curves (Berutti et al. 2009). The disrespect of the original anatomy can lead the clinician to miss preparation objectives: remove remaining pulp tissue, eliminate microorganisms, remove debris and shape the root canal(s) so that the root canal system can be cleaned and filled. . (European Society of Endodontology 2006)

To compare the canal anatomy after different mechanical preparations and to evaluate the maintenance of its original shape, simulated canals were used to standardize experimental conditions, but always regarding the fact that this method only gives 2D dimensions. Despite the fact that resin blocks may not always reflect the action of the instruments in root canals of real teeth because of the many different configurations, the S-shape canal used, has been reported to be of use in pointing up differences in performance of instruments, possibly as a result of the increased difficulty of instrumentation. (Berutti et al. 2009; Yoshimine et al. 2005).

The first stage of the study comprised a quantitative analysis through observation of changes between pre instrumentation and post instrumentation curvature followed by a qualitative observation of any canal aberrations concerning the presence of straightening curves and apical transportation. The experimental method used appeared to be reliable in representing changes in canal curvature and for extrapolating the results, however, this analysis may not be completely accurate taking in consideration:

1. The uncertainty degree of the Rhinoceros Software, considering 0,006;

2. Data dependent on operator's accuracy on prosecuting the experimental procedure:

2.1 Maintenance of the exact working length;

2.2 Stabilization of the resin block during the mechanical preparation

ProTaper Gold™ produced significantly less modification in coronal and apical canal curvature compared ProTaper Universal™. When comparing ProTaper Next™ and ProTaper Universal™, the results of the first system show less modification in coronal and apical canal curvature compared to the second one. This results are consistent with Shori et al. 2015 conclusions, which says that ProTaper Next™ can induce less dentinal defects than ProTaper Universal™. Therefore, under the study conditions, it might be assumed that ProTaper Gold™ is the rotary system that has more respect for original canal anatomy. Higher flexibility might be the predominant property responsible by the system's facility to maintain the canal's original anatomy. Despite the identical architecture and operation of the ProTaper Gold™ and ProTaper Universal™ systems, the different manufacturing processes of the instruments clearly affect their flexibility, stress-strain distribution patterns and fatigue resistance behavior. (Hieawy et al. 2015).

Every system file, proportionally, removes more resin in the apical curve than in the coronal.

No macroscopic deformations or fractures of any instrument, mechanical or manual, occurred during the experiment.

The second stage of the study comprised a qualitative analysis where endodontists, inexpert clinicians and students evaluated coronal apical curvatures rectification and apical transport. The differences registered are due to clinical experience and different levels of endodontic knowledge. The more significant result was the evaluation of apical transportation by ProTaper Gold™, where its maintenance was confirmed only by the endodontists. Apical curvature straightening by ProTaper Universal™ and the maintenance of the original canal anatomy by ProTaper Gold™ are consistent with the quantitative results and between the different blinded examiners. ProTaper Universal™ and ProTaper Next™ were responsible for some apical irregularities.

6. CONCLUSIONS

With the optimization of the microstructure and behavior transformation of the NiTi alloys, allied to the advances in mechanical properties with the development of metallurgy, becomes essential to realize witch are the reliable instruments in the market that best fit our expectations.

Under the limitations of this study, ProTaper Gold™ was the rotary file system which best maintained the original anatomy of the S-shaped canal with less modification of coronal and apical curvatures, reveling more flexibility compared to ProTaper Next™ and ProTaper Universal ™ systems.

ProTaper Universal ™ was the system that originated the greatest modification of the original canal, presenting a significant tendency to straighten apical curvature.

During clinical practice, clinicians should be aware of the mechanical properties of the instruments chosen to best adapt a rotary system file to a specific case. It is important to respect the canal’s original anatomy and avoid apical transportation so the endodontic treatment won’t be compromised.

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M-Wire Brochure

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APPENDIX

Abbreviations

2D – two dimensional

NiTi – Nickel-Titanium

ICC – inner coronal curvature

OCC – outer coronal curvature

IAC – inner apical curvature

OAC – outer apical curvature

Symbols

% - percentage

p - significance

® - registered trademark

TM - unregistered trademark

Units

mm - millimeters

N cm - Newton centimeter

rpm - rotations per minute

FIGURE INDEX

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CHART INDEX